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13. ABSTRACT (Maximum 200 words)

Accurate measurements of coordinated human head/eye/hand actions were made as subjects manipulated or fixated objects within arms' reach. Both tasks were performed under natural conditions in that: (i) binocular gaze was recorded with the upper body free from restraints, and (ii) the objects serving as stimuli for the visually-guided motor responses were near the subject's head (< 1 m). Accurate gaze under these conditions required that even the smallest movements of the head were compensated by carefully coordinated conjunctive/disjunctive (version/vergence) eye movements. Conditions like these are particularly important for human beings, whose ability to design, fabricate and use tools have given them unmatched mastery of their environment. Making accurate measurements under these conditions was novel. It required unique instrumentation developed and only available at the University of Maryland, College Park. Research completed on this grant showed that the large literature on human oculomotor performance, based mainly on recordings made under unnatural conditions (monocular input, a restrained head and targets beyond arms' reach), tends: (i) to underestimate both the flexibility and capacity of the oculomotor system, and (ii) to obscure its preferred mode of operation under the conditions that made it possible for humans to evolve their exceptional manipulative skills.

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Research Objectives

This grant had two main thrusts: **I:** It investigated the effectiveness of different compensatory oculomotor mechanisms that place and keep, *gaze* (the line-of-sight in space) on objects near enough to be touched. These compensatory mechanisms allow such objects to be scrutinized and manipulated, and **II:** it investigated how oculomotor control and visually-guided manipulations are affected by both high- and low-level factors, *viz.*, sensory/perceptual, cognitive and volitional. The problems that motivated these investigations will be described next.

If an individual wants to *maintain gaze* in order to examine an object very carefully, the oculomotor system must correct *gaze-errors* (differences between gaze and object position) caused by unavoidable changes of the position of the head relative to the object being examined. Oculomotor mechanisms must also compensate for head movements when gaze shifts from one object to another. Here, failure to compensate prevents gaze from falling directly on the intended object, causing an *initial gaze-shift error*. Such errors lead to inefficient search and manipulations because they make it necessary to make additional "corrective" saccades. This need slows search down and disturbs the fluency of ongoing, visually-guided manipulations.

Oculomotor compensation increases in importance as objects come nearer. When they are near enough to be reached, even very small changes of head position require relatively large compensatory eye movements. Potential compensatory oculomotor mechanisms include: (I) *VOR and LVOR* (the vestibulo-ocular *reflexes*) and (ii) *coordinating motor programs* (templates for generating coordinated head/eye/torso/hand motor actions). These templates might be brought to each novel coordinated motor task with movement size and/or direction already calibrated, or calibrated as the task is learned.

Three years ago, little was known about oculomotor compensation under the relatively natural conditions employed in this research. These conditions were *natural* in that an unrestrained, seated subject was required to look carefully at or manipulate nearby objects. These conditions are particularly important for humans, whose design, fabrication and use of tools have given them unmatched mastery of their environment. Despite this fact, little was known about the way humans perform visually-guided manipulations under such natural conditions. This research set out to fill this gap.

Many of the experimental results produced by this grant could not be anticipated from knowledge accumulated in the large literature describing experiments done under unnatural

conditions. Prior to the work done on this grant, most researchers studied subjects who viewed distant objects monocularly with their heads almost completely immobilized by biteboards or chinrests. What *was* known about compensatory eye movements three years ago when this research began?

It was known that *VOR* was relatively effective. It compensated 92 to 98% of the gaze error that could have been introduced, when large head oscillations (~ 40° p-p) were made while gaze was maintained on objects beyond reach (Steinman & Collewijn, 1980; Steinman, Levinson, Collewijn & Van der Steen, 1985). Its effectiveness with nearby objects was not known, nor was its operation during gaze-shifts among objects. There was also controversy about its operation beyond arms' reach. Some experts held that *VOR* was "switched-off" during gaze-shifts. Others held that it was "on", but unreliable. Still others held that it was "off," but that another, unnamed, mechanism compensated for head movements during gaze-shifts. (See Epelboim, Kowler, Steinman, Collewijn, Erkelens, & Pizlo, 1995 a, for a review of this controversy, as well as for details of the new research that will only be summarized below.)

The contribution of the *LVOR* (the Linear VOR) was also unclear. This compensatory mechanism is a new addition to the oculomotor literature (Paige, 1989; 1991). It is not as well established as the *VOR*. A compensatory mechanism for head translations, like the *LVOR*, becomes very important with near objects because small translations of the head require large compensatory rotations of the eye . Translational components, associated with head rotations, are also contribute to gaze errors when objects are within reach. It is clear that the *VOR*, alone, cannot provide complete compensation.

Motor programs could also compensate for bodily movements. A new motor program might have to be learned during each novel task, or, it might be brought to the task in the form of calibrated head/eye/torso/arm maps. These might allow a novel task to be executed by invoking a known strategy and making only parametric adjustments specific to the particular situation. For example, the subject might say to himself, "the farthest object can be reached while sitting upright", or, alternatively, "it is too far, lean forward to reach it". The presence of such strategies and calibrated motor programs might allow *VOR, LVOR* to be "switched-off" during gaze-shifts as has been proposed (see above).

Note, however, that the availability of one or another of these compensatory reflexes does not, in itself, preclude the existence of other compensatory mechanisms. All could be available and useful. This research program began by making a simplifying assumption. Namely, that the vestibulo-ocular reflexes, *if available under the natural conditions studied,*

would be sufficient and could, therefore, serve as the primary, perhaps even only, compensatory mechanisms. Beginning with this assumption was useful because it allowed concentration on the second goal, *viz.*, to find out how motor programs, used to accomplish purposeful manipulations, are affected by high- and low-level factors. Finding out how existing motor programs *also* contributed to establishing and maintaining gaze could be postponed.

This assumption can be justified. Namely, if the vestibular reflexes are available, compensatory motor programs, pre-calibrated or not, would be redundant, perhaps superfluous. The assumption that *both* motor programs and vestibular reflexes would be available goes counter to the criterion most oculomotor scientists prefer. Most believe that biological control systems tend to be as simple as possible, so once reflexes can do the job on-line, why add the capacity to learn novel motor programs to accomplish the same thing?

With this consideration in mind, the first experiment examined the availability of the vestibular compensatory mechanisms under natural, but until then never studied, conditions. This experiment led to the publication by Epelboim *et al.* (1995 a) cited above. A publication on the dynamics of vergence and version was also published by Collewijn, Erkelens & Steinman(1995). A paper by these authors on binocular trajectories (an extension of this research) was published in 1997. Both papers deal with the nature, rather than the availability, of the oculomotor compensatory reflexes. They examined the manner in which the high and low velocity subsystems interact when gaze shifts among objects within arms' reach. These publications solved some existing problems, but, raised a host of new questions. Some are motivating ongoing research.

Experiments bearing on the second thrust were run concurrently, *i.e..*, studies of the effects of low- and high-level factors on visually-guided manipulations. These experiments have produced so far, one publication (Epelboim, Steinman, Kowler, Edwards, Pizlo, Erkelens & Collewijn, 1995 b), an "in press" *ms* by these authors, and an accepted *ms*, authored solely by Dr. Epelboim, who completed her doctoral degree as an AASERT student on this grant. All three papers derive from Dr. Epelboim's doctoral dissertation. This dissertation won the Bartlett Award for the best Ph.D. dissertation completed in the Department of Psychology at the University of Maryland in 1995 (12 Ph.D. in Psychology were awarded that year) . Highlights of this research will be described next.

Highlights of Publications and Other Finished Work

I. The effectiveness of compensatory reflexes during and between gaze-shifts: (a) The gaze of unrestrained subjects was recorded as they shifted gaze among three widely-separated targets, all within arms' reach. These initial gaze-shift errors were compared to errors observed when an unexpected push, produced a head movement during the gaze-shift. This was done by having an experimenter, seated behind the subject, push the subject at unpredictable times in unpredictable directions as gaze was shifted in time to a metronome. The metronome made it possible for the experimenter to predict when a gaze-shift would make the head move. The

experiment required that the head was moving relatively fast *while* gaze was actually shifting. This seldom happened because saccades are very fast. Even the relatively large saccades (31°-59°) required in this experiment took less than 100 ms to complete. This made it very unlikely that a head movement would occur during a gaze-shift. A large number of saccades were necessary to gather an adequate number of what were called, "golden" observations. Two subjects ran about 100 trials (≈900 saccades each) before a suitable sample of golden gaze-shifts was recorded.

Analyses of both subject's data showed that vestibular compensation *was* effective, albeit: variable; sometimes compensating on only one meridian, and (ii) compensating by varying amounts in the presence of similar head velocities. Vestibular reflexes also established gaze following a gaze-shift as well after a passive displacement as it did when no passive head displacement was introduced. Initial gaze-shift errors were also "normal" also showing on-line vestibular compensation. These initial errors were normal in the sense that they were similar to errors following saccades of similar size with the head on a biteboard (Collewijn, Erkelens & Steinman, 1988 a, b).These findings make it reasonable to assume that compensatory vestibular reflexes are likely to operate during visually-guided manipulations. This assumption, however, must still be tested. This can be done by introducing unexpected, passive displacements while tapping or some similar manipulation is performed.

(b) In another paper, Epelboim (in press) showed that the average retinal image velocity is relatively low (< 1.5°/s), when a subject sits with the head free, while maintaining gaze on a nearby object. Velocities like this are low enough to prevent them from having adverse effects on visual acuity (Westheimer & McKee, 1975; Murphy, 1978; Steinman *et al.*, 1986; Steinman & Levinson, 1990). This finding was new, but more reassuring than surprising. Human scrutiny of small, nearby objects would be inconvenient, to say the least, if the head had to be immobilized before gaze could be maintained. So, common sense, buttressed by subjective impressions, led to the expectation that compensation would be good, when a human being maintained gaze on nearby objects. But, prior to this experiment, the degree to which gaze could be maintained had only been measured accurately with distant targets. It is reassuring, even if not surprising, to know that vestibular compensation is also functionally effective when objects are near. Here, great demands are made on compensatory reflexes. These demands include the need to compensate for even small head translations. Compensation is not needed to maintain gaze when the target object are far away, the only condition studied previously.

II. Effect of Low- and High-Level Factors on Visually-Guided Manipulations: (a) Virtually nothing was known about visuomotor coordination under the natural conditions employed because, until very recently, binocular gaze could not be measured *accurately* and *precisely*, while nearby objects were manipulated with the head free to move naturally. The criterion for *accurate* and *precise* measurement used is the same as the criterion used elsewhere in experimental sciences. Namely, accurate measurements of head and eye angular orientations and head translations (variables needed to estimate gaze with the head free) must be made *in engineering units on a scale finer, and with instruments less variable, than the performance being measured.* At its limit, human oculomotor performance is exquisite.

Average absolute gaze-error during maintained fixation and its standard deviation are both only about 2 to 3 minarc when the head cannot move. Knowing this, measurements were needed that were better by at least a factor of two, *i.e.*, 1 to 1½. Meeting this criterion required some effort, expended over many years, being in place a year or two before this grant began.

Highlights of this research are: (i) just looking at a sequence of targets, solely with the objective of fixating each target accurately, and looking at a similar sequence with the objective of tapping the targets, are fundamentally different tasks. The seemingly more complicated task, using vision to guide tapping, was easier, more pleasant and took less time to complete than the task in which the subject did much less; namely, fixated each target in a sequence for its own sake; (ii) visual search (using a saccade to find the next target) is a separate and different saccadic activity than looking from one target to the next in the sequence in both kinds of tasks, (iii) looking for its own sake, looking to guide tapping, and visual searching is synergistic, they interact in beneficial ways, and (iv) subjects almost always look at the target they are about to tap before tapping it, but are convinced that they do not do this often once the particular target pattern has been learned (see Epelboim *et al.*, 1995 b).

Other analyses showed that gaze-shift-dynamics were adjusted differently in each task. This result suggests that the objective (purpose or goal) of a given task sets the parameters of oculomotor mechanisms to produce optimal, *i.e.*, efficient performance. Subjects were not aware of doing this, implying that the required parameter values were determined and conveyed to the oculomotor "plant" automatically (Epelboim *et al.*, in press). This was true both for shifting gaze (Epelboim *et al.* 1995 a) and for maintaining gaze in place. In the latter, the task's purpose determined and set parameters of *slow control* (Steinman *et al.*, 1973) to allow the amount of retinal image slip to be different, but optimal, optimal in the sense that it led to efficient performance of the particular task.

In some tasks, slow control actively maintained the direction of gaze between gaze-shifts, but in others gaze moved with the head, *i. e.,* slow control was not active. Both the head and eyes moved differently in different tasks. The nature of their coordination depended on what the subject was asked to do. The advantages inherent in doing this, as well as the appropriate parameter-settings needed by the oculomotor "plant" were brought into the experimental setting by the subjects. These adjustments were made without either training or conscious effort. This kind of adaptabilty comes very naturally and the humans' capacity to perform automatically in this flexible manner is probably responsible, in no small part, for his exceptional success at manipulations, ranging from chipping flints to fabricating watches, to say nothing of the manipulations performed these days during microsurgery.

Additional Published Research: Occasionally, time was freed-up by the need to develop software and/or to analyze gaze-data before moving on with projects directly related to the main thrusts of this grant. Most of this "free" time was used to complete a series of experiments on the role of eye movements during reading. This is an important problem at the interface of oculomotor and cognitive processes. It had been studied very intensively, but very crudely, for at least 20 years. Research completed thus far on this grant should revitalize research in the reading area. It also led to an insight that may prove to be important for this

research program.

Specifically, the exceptionally accurate eye movement recording instrumentation available in this laboratory was used to examine the role of spaces in guiding reading eye movements. The results obtained were controversial. One might even say, "revolutionary" in that they shifted the explanatory emphasis back to the importance of cognitive factors in guiding the eye movement pattern during reading. Prior to this work, low-level features, such as spaces between words, had dominated thinking about the reading eye movement pattern since the mid 1970s, when it first became possible for reading researchers, without training in recording human eye movements, to use off-the-shelf eye-trackers to make, what they believed to be, accurate recordings of the eye movements used to read.

N.B., this work on role of high- and low-level factors in the reading eye movement pattern may prove to be important for future research directly related to the main thrusts of this grant. The reading result suggests that cognitive factors may play a more important role than local factors when displays are scanned for the purpose of abstracting meanings from symbols that represent states and/or events at local and remote locations. This possibility is only a hunch at this time. Considerable thought and some pilot work will be necessary before this lead is likely to be followed up when "free-time" develops in the future. The main publications based on this reading research are: Epelboim, Booth & Steinman (1994); Epelboim, Booth & Steinman (1996); Epelboim, Booth, Ashkenazy, Taleghani & Steinman (in press).

Uniqueness of Approach: This research was made possible by unique instrumentation (the Maryland Revolving Field Monitor, MRFM) developed and available only at the University of Maryland, College Park. See Edwards *et al.* (1994) for full details, or Epelboim *et al.* (1995 b) for a briefer treatment. This kind of research probably cannot be done anywhere else with anything like comparable accuracy and precision in an unrestrained subject. Being able to make these measurements allows us to look, for the first time, at characteristics of human visually-guided motor performance with sufficient spatial and temporal resolution to examine the finest performance details as new skills are learned and preserved.

The approach is also somewhat unusual because the limits of sensory and motor capacity are studied. No attempt is made to establish populational norms. In almost all cases, subjects, who know the purpose of the experiment and the relevant literature, participate in these experiments. The data of each individual are reported separately. Individual differences are explained, whenever possible, never obscured by averaging across subjects. This approach is common in the visual science community, but less so in the diverse group studying eye movements. This approach also follows as a natural consequence of using instrumentation that provides accurate measurements of gaze , *i.e.*, this instrumentation requires: (i) attachments to the eyes: It is "invasive," so scientifically-educated, mature adults are best able to give "informed consent"; (ii) short recording sessions (<40 minutes) that more often than not must be replicated a number of times; (iii) careful, time-consuming, psychophysical calibrations of the sighting centers of each eye within the apparatus (see appended "Green Book" describing this instrumentation), and (iv) commitment to participating in experiments that sometimes take more than a year to complete.

Summary: Our research uses unique instrumentation to examine, until now hidden, fine-scale characteristics of coordinated human actions in nearby 3-D space. The upper body is free from artificial restraints, allowing us to see natural 3-D search and action patterns. The research completed on this grant has already shown that observations made with the restraints used in other studies of eye movements underestimate the capacity of the oculomotor system, and also obscure its preferred modes of operation.

The exceptional motor skills developed by our species have been a major contributor to the control human beings now exercise over many aspects of their environment. This laboratory studies the development of such skills at a level of analysis sufficient to see all of their potentially important details. Knowledge, based on such studies, should be useful as well as intellectually satisfying, in the long run. The long range goal is to understand how sensory/perceptual, cognitive and motor processes, both reflexive and learned, work together during visually-guided manipulative tasks -- tasks performed within arms' reach, the region in which the exceptional skill and creativity of human beings are manifest. Said even more simply, the long range goal is to find out how specific signals, plans and decisions are used to make human manipulations efficient, adaptable and, occasionally, even creative. When this goal is reached, that is, when the knowledge needed to emulate a human operator is available, it should be possible to develop electromechanical surrogates, capable of performing similar tasks skillfully in novel environments.

Publications 1994-97

Refereed Archival Journals

Epelboim, J., Booth, J. & Steinman, R. M. (1994) Reading unspaced text: Implications for theories of Reading. *Vision Research, 34*, 1735-1766.

Epelboim, J., Kowler, E., Steinman, R. M., Collewijn, H., Erkelens, C. J. & Pizlo, Z. (1995 a). When push comes to shove: compensation for passive perturbations of the head during natural gaze shifts. *Journal of Vestibular Research, 5*, 421-442.

Epelboim, J., Steinman, R. M., Kowler, E., Edwards, M., Pizlo, Z., Erkelens, C. J. & Collewijn, H. (1995 b). The function of visual search and memory in sequential looking tasks. *Vision Research, 35*, 3401-3422.

Pizlo, Z., Rosenfeld, A. & Epelboim, J. (1995) Exponential model of the time-course of size processing. *Vision Research, 35*, 1089-1107.

Collewijn, H., Erkelens, C. J. and Steinman, R. M. (1995) Voluntary binocular gaze-shifts in the plane of regard: dynamics of version and vergence. *Vision Research, 35*, 3335-3358.

Epelboim, J., Booth, J. R. Booth & Steinman, R. M. (1996) Much ado about nothing: The place of space in text. *Vision Research, 36*, 465-470.

Collewijn, H., Erkelens, C.J. & Steinman, R. M. (1997) Trajectories of the human binocular fixation point during conjugate and non-conjugate gaze-shifts. *Vision Research,* 37, 1049-1069.

Epelboim, J., Booth, J. R., Ashkenazy, R., Taleghani & Steinman, R. M. (in press) Fillers and Spaces in text: The importance of word recognition during reading. *Vision Research, 37.*

Epelboim, J., Steinman, R. M., Kowler, E., Pizlo, Z., Erkelens, C. J. & Collewjn, H. (In press) Gaze-shift dynamics in two kinds of sequential tasks. *Vision Research, 37.*

Epelboim (in press) Gaze-stability in two kinds of sequential tasks. *Vision Research, 38.*

Book Chapters

Collewijn, H., Erkelens, C. J., Z. Pizlo, Z. & Steinman, R. M. (1994) Binocular gaze movements: coordination of vergence and version. In: Edited by Ygge, J. & Lennerstrand, G. *Eye Movements in Reading*, (Wenner-Gren International Science Series: Vol. 64), Pergamon, Oxford, pp. 97-115.

Steinman, R. M. (1995) *Moveo ergo video*: Natural retinal image motion and its effect on vision. In: Edited by Landy, M. S., Maloney, L. T. and Pavel, M. *Exploratory Vision: The Active Eye*, Springer-Verlag, New York, pp. 3-50.

Refereed Conference Proceedings

Epelboim, J., Collewijn, H., Edwards, M., Erkelens, C. J., Kowler, H., Pizlo, Z., & Steinman, R. M. (1994) Natural oculomotor performance in looking and tapping tasks. *Proceedings of the Cognitive Society, 16*, 272-277.

Epelboim, J., Booth, J. R. & Steinman, R. M. (1995) The relative importance of spaces and meaning in texts. *Proceedings of the Cognitive Society, 17*, 533-588.

Epelboim, J., Epelboim, J., Taleghani, A., Ashkenazy, R. & Steinman, R. M. (1996) Effects of irrelevant symbols in text on word recognition and saccadic programming during reading. *Proceedings of the Cognitive Science Society, 18*, 760-766.

References Cited in Text Not Listed Above

Collewijn, H., Erkelens, C. J. & Steinman, R. M. (1988 a) Binocular co-ordination of human horizontal saccadic eye movements. *Journal of Physiology (London), 404*, 157-182.

Collewijn, H., Erkelens, C. J. & Steinman, R. M. (1988 b) Binocular co-ordination of human vertical saccadic eye movements. *Journal of Physiology (London), 404,* 183-197.

Edwards, M., Pizlo, Z., Erkelens, C. J., Collewijn, H., Kowler, E., Stepanov, M. R. &

Steinman, R. M. (1994) The Maryland Revolving-Field Monitor -- Theory of the instrument and processing its data. *Technical Report CAR-TR-711*, Center for Automation Research, University of Maryland, College Park, pp. 1-129.

Murphy, B. (1978) Pattern thresholds for moving and stationary gratings during smooth eye movement. *Vision Research, 18*, 521-530.

Paige, G. D. (1989) The influence of target distance on eye movement responses during vertical linear motion. *Experimental Brain Research, 77*, 585-593.

Paige, G. D. (1991) Linear vestibulo-ocular reflex (LVOR) and modulation by vergence. *Acta Otolaryngolgia, 481*, 282-286.

Steinman, R. M. & Collewijn, H. (1980)Binocular retinal image motion during active head rotation. Vision Research, 20, 415-429.

Steinman, R. M. & Levinson, J. (1990) The role of eye movement in the detection of contrast and detail. In: *Eye Movements and their Role in Visual and Cognitive Processes.* Edited by E. Kowler, Elsevier Science (Biomedical Division, Amsterdam, pp. 115-212.

Steinman, R. M., Levinson, J., Collewijn, H. & Van der Steen (1985) Vision in the presence of known natural retinal image motion. *Journal of the Optical Society of America, A. 2*, 226-233.

Steinman, R. M., Haddad, G. M., Skavenski, A. A. & Wyman (1973) Miniature Eye Movement. *Science,* 181, 810-819.

Westheimer, G. & McKee, S. (1975) Visual acuity in the presence of retinal image motion. *Journal of the Optical Society of America, 65*, 847-850.

Professional Personnel, Inculding Honors & Competitvie Awards

Supported Partially by Grant:

Robert M. Steinman, D. D. S., Ph. D., Professor of Psychology and PI, University of Maryland.

Fellow, American Psychological Society, 1994.

UMCP Chapter, Sigma Xi, Lifetime Contribution to Science Award, 1996.

Julie Epelboim, Grad. Res. Asst., Ph.. D., Awarded December 1995, supported from September 1, 1990 - December 15, 1995 (AASERT 1992-94).

Won NIH-NRSA Individual Post-doctoral Fellowship Award to permit study at the Center for the Study of Language and Information at Stanford under the Sponsorship of Prof. P. Suppes, NAS Fellow & National Medal of Science Winner.

Michael Stepanov, Grad. Res. Asst., University of Maryland, made good progress towards his Ph.D., while supported by the grant between September 1994 - February 1997, when circumstances forced him to take a leave for one year to help his parents, who were experiencing severe financial hardships in Russia.. He completed all the course-work required for the Ph.D. and satisfied the requirement for "Research Competency" before going on leave. When he returns from leave he will need only to pass his doctoral comprehensive exam and complete an acceptable doctoral dissertation to complete his degree.

Tatiana I. Forofonova, M.D., Ph.D., D. Med. Sc., joined the grant as a "Visiting Senior Research Scientist" in March 1996. She joined the lab to learn about eye movement research and basic visual science. In Moscow, she practiced as a laser surgeon as well as being active in a wide range of administrative, research, teaching and clinical activities. She was a very useful addition to this project. Her ophthalmology training makes make her exceptionally adept at handling the SKALAR silicone annuli used in this research. She got her "green card" in July 1996, and participated on the grant as a "Senior Research Scientist" (on a part-time, hourly basis) since then. Recently, Dr. Forofonova decided that she would like to pursue a formal course of study leading to a Ph.D. in Psychology as she collaborates with us. She was admitted to our graduate program and will begin her studies on August 16, 1997.

Arash Taleghani and Rebecca Ashkenazy, were Undergraduate Research Assistants paid on an hourly-basis. They contributed in many ways to the scientific work in the lab, ranging from helping to run experiments, analyzing data, preparing graphs, drafting reports etc.. Both graduated May 1997. Ms. Ashkenazy will enter Johns Hopkins Medical School in the Fall. Mr. Taleghani is now working in a psychiatric hospital as he awaits admission to medical school. Both contributed sufficiently to the research on reading to earn status as co-authors. Their contributions to other projects were acknowledged in a number of other publications.

Active Participants, but with No Remuneration from this Grant:

Han Collewijn, M. D., Ph. D., Co-PI; Prof., Physiology & co-PI, Erasmus U. Rotterdam, NL

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Zygmunt Pizlo, Ph. D.(E.E.), Ph. D. (PSYC), Assoc. Prof., Psychol. Science, Purdue U.

Won the 1994 Young Investigator Award from the Society for Mathematical Psychology on the basis of publications derived from his doctoral dissertation completed while supported as a Graduate Research Assistant on the prior AFOSR Grant.